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## A METHOD OF REDUCING THE EFFECT OF DISTURBANCES IN THE GALVANOMETER BRANCH OF A POTENTIOMETER CIRCUIT

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### ABSTRACT

The method described automatically eliminates the effect of a thermoelectromotive force in the galvanometer branch and doubles the sensitivity of the galvanometer to a lack of balance of the potentiometer, thus reducing to half the effect of various types of electrical and mechanical disturbances.

In the measurement of small electromotive forces by means of a potentiometer, disturbances in the galvanometer branch frequently limit the accuracy attainable or increase the difficulties in obtaining a specified accuracy. These disturbances may be electrical or mechanical. In addition, the accuracy of the measurements may be limited by the sensitivity of the galvanometer or by the optical system of the galvanometer. Usually the most important disturbing factor in the galvanometer and other parts of the galvanometer branch is a thermoelectromotive force.

Under favorable conditions this thermoelectromotive force has a value in the range from  $+1$  to  $-1$  microvolt. When exceptional precautions are taken and an "all-copper circuit" galvanometer is used, this electromotive force usually has a value in the range from  $+0.1$  to  $-0.1$  microvolt. If, therefore, the accuracy of measurement is to be of the order of  $0.01$  microvolt, something in addition to the taking of exceptional precautions must be done to avoid the inclusion of the thermoelectromotive force in the galvanometer branch with the electromotive force being measured.

Various methods have been used in measuring or compensating the thermoelectromotive force in the galvanometer branch or galvanometer branch and potentiometer. The method most generally used<sup>1</sup> consists in balancing the potentiometer in the usual way and then making a second balance after reversing connections to the battery and to the source of the electromotive force being measured. The difference between the two readings of the potentiometer thus obtained is equal to twice the thermoelectromotive force in the galvanometer branch and potentiometer. The double measurement gives a correction which may be applied to each of a series of measurements, provided the thermoelectromotive force in the galvanometer branch and potentiometer remains constant throughout the series.

<sup>1</sup> H. Diesselhorst, *Z. Instrumentenk.* **28**, 7 (1908).

Another method consists in using a so-called "neutral resistor" and so-called "false zero" of the galvanometer.<sup>2</sup> This consists in replacing the source of the electromotive force being measured by a resistor which has the same resistance as the source and contains no source of electromotive force. Then with the battery circuit of the potentiometer open and the high sensitivity key in the galvanometer circuit closed, the scale of the galvanometer is so adjusted that the scale reading is zero. The same end is accomplished if, instead of adjusting the scale, the scale reading is noted and used as a zero. Each of these methods requires the use of a neutral switch, which will not introduce additional thermoelectromotive forces into the circuit.

Still another method consists in introducing into the galvanometer branch a potential drop equal in magnitude to the thermoelectromotive force but of opposite polarity.<sup>3</sup>

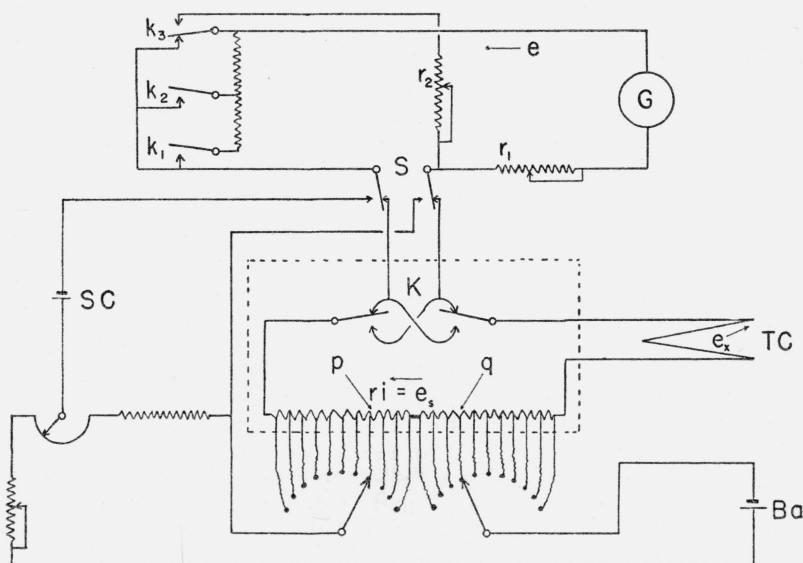


FIGURE 1.—Potentiometer circuit showing double-pole double-throw key,  $K$ , in its relation to the galvanometer, thermocouple, and resistors of the potentiometer.

In the first of these methods the thermoelectromotive force is measured. In the second and third it is compensated, but the compensation is accomplished in a different way. In the use of these methods, the thermoelectromotive force must be measured or compensated more or less frequently, depending on its rate of change and the accuracy desired in the measurements. A method which requires neither measurement nor compensation may be understood by a consideration of the circuit shown in figure 1. In this figure

$G$ , the galvanometer

$r_1$ , a resistor whose resistance together with other resistances in galvanometer circuit results in a suitable damping of the galvanometer;

$r_2$ , a resistor for damping the galvanometer when the galvanometer keys are open;

<sup>2</sup> W. P. White, Phys. Rev. 25, 344 (1907).

<sup>3</sup> H. B. Brooks and A. W. Spinks, BS J. Research 9, 781 (1932) RP506.

$k_1$ ,  $k_2$ , and  $k_3$ , (low, intermediate, and high sensitivity) galvanometer keys

$M$ , a double-pole, double-throw switch for changing the connection of the galvanometer from that used in measurements to that used in adjusting the current through the potentiometer;

$SC$ , standard cell;

$K$ , a double-pole, double-throw key necessary for the use of method described here;

$Ba$ , the battery supplying the test current.

The portion of the circuit shown in the dotted rectangle is enclosed in a thermal shield and in general is so constructed as to be, with a normal ambient temperature, practically free of thermoelectromotive force. A construction resulting in an almost complete elimination or balance of thermoelectromotive forces has been described by Brooks and Spinks.<sup>4</sup> What has not been described previously is the double-pole double-throw key,  $K$ , and the method (or general procedure) used in establishing balances of the potentiometer. Inasmuch as a key suitable for use with the method is described in the following paper,<sup>5</sup> no detailed description will be given here. However, to fully realize the advantages of the method it should be understood that the key must be so constructed that a reversal of connections may be made in a time which is very short relative to the period of the galvanometer. During a reversal of connections, the resistance to an electromotive force in the galvanometer branch is either increased to infinity or decreased by an amount corresponding to the resistance of the "measuring circuit" of the potentiometer, plus the resistance of the source of the electromotive force being measured. Consequently, unless the reversal of connections is made quickly, the momentary decrease or increase of the current through the galvanometer will set the galvanometer coil in motion.

One of several possible ways of obtaining quick reversals of connections, without introducing objectionable features, is a construction such as is shown schematically in figure 2. It will be noted that connections are reversed without opening the circuit. Furthermore, the contacts,  $s$ , which also serve as stops, may be so adjusted that as the operating button is depressed or released the two halves of the switch change connections at substantially the same instant. It should be understood that the two halves of the key, instead of being placed end to end as shown, would be oriented in the same direction and placed side by side.

The general procedure in establishing a balance of the potentiometer is as follows:

1. The customary procedure is used up to the point at which with the full sensitivity of the galvanometer the deflection is not excessive. However, it is desirable that the galvanometer scale be so adjusted that the scale reading, with the keys  $k_1$ ,  $k_2$ , and  $k_3$  open (see fig. 1), differs considerably from zero or that the scale have its zero at one of its ends.

2. The key,  $k_3$ , is closed and from this point on is kept locked in the closed position.

<sup>4</sup> See footnote 3.

<sup>5</sup> R. P. Teele and S. Schuhmann, *A potentiometer for measuring voltages of 10 microvolts to an accuracy of 0.01 microvolt*, NBS J. Research **22**, 431 (1939) RP1195.

3. The potentiometer is so nearly balanced that the scale reading of the galvanometer becomes approximately the same as the initial scale reading.

4. With the key,  $K$ , alternately in one and then in the other of its two possible positions, for periods of time corresponding approximately to the period of the galvanometer, the potentiometer is so balanced that in the judgment of the observer the deflection of the galvanometer is not affected by changes in the position of the key, even though it may be affected by one, two, or more of several possible disturbing factors.

These four steps constitute a method of reducing the effect of disturbances in the galvanometer branch of a potentiometer circuit.

To see what is accomplished by the use of this method, consider first the case in which the only disturbing factor is a constant thermo-electromotive force in some part of the galvanometer branch.

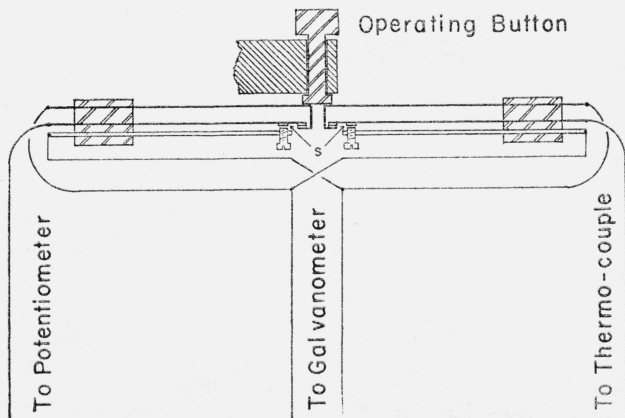


FIGURE 2.—Quick-acting double-pole double-throw key.

Let  $d_0$  = the scale reading corresponding to the mechanical zero of the galvanometer, that is, the scale reading which would have been obtained had the galvanometer circuit been opened at a point between the galvanometer and  $r_2$  either just before or just after the establishment of a balance of the potentiometer,

$d_1$  = the scale reading with the key,  $K$ , in the position shown in figure 1

$d_2$  = the scale reading with the key,  $K$ , in the other position

$r$  = the resistance of the potentiometer between potential and current branch points, that is, between  $p$  and  $q$  in figure 1

$i$  = the current in the potentiometer

$e$  = the electromotive force in the galvanometer branch

$e_s = ri$

$e_x$  = the electromotive force being measured

$V$  = the change in the scale reading resulting from unit change in the electromotive force in the galvanometer circuit.

With the key,  $K$ , in the position in figure 1

$$d_1 - d_0 = V(e + e_x - e_s). \quad (1)$$

With the key,  $K$ , in the other of its two possible positions

$$d_2 - d_0 = V(e - e_x + e_s). \quad (2)$$

From eq 1 and 2 it follows that

$$d_1 - d_2 = 2V(e_x - e_s). \quad (3)$$

Consequently, if

$$d_2 = d_1, \quad e_x = e_s. \quad (4)$$

Equation 3 shows that the method obviates adjustments and readings of the galvanometer scale with either the galvanometer keys,  $k_1$ ,  $k_2$ , and  $k_3$ , open or the galvanometer circuit open, automatically eliminates the effect of the thermoelectromotive force in the galvanometer branch, and in effect doubles the sensitivity of the galvanometer to a lack of balance of the potentiometer. The method also automatically eliminates the effect of the thermoelectromotive force in the resistor,  $r_2$ , and the key,  $k_3$ , when in either the open or closed position.

Continuing with the assumption that the only disturbance in the galvanometer branch is an electromotive force, if, in step 4 of the method, after the best possible adjustment of the potentiometer has been made, it is found that successive values of  $d_1$  and  $d_2$  are larger or smaller by approximately equal amounts, it is an indication that the electromotive force in the galvanometer branch is changing while the potentiometer is remaining balanced. Obviously, therefore, it is possible to establish accurate balances of the potentiometer even when the electromotive force in the galvanometer branch is changing, provided it changes slowly and at a fairly uniform rate. If, on the other hand, it is found that successive alternate differences between  $d_1$  and  $d_2$  are increasing or decreasing by approximately equal amounts, it is an indication that the electromotive force being measured is changing or that the current through the potentiometer is changing. Consequently, if the scale reading is changing gradually and in a fairly regular way, it is possible to determine whether the cause is changes in the electromotive force in the galvanometer branch or changes in the balance of the potentiometer.

The effects of other types of disturbances, such as mechanical vibrations, electromotive forces induced by neighboring circuits or by movement of the galvanometer leads in the earth's magnetic field and of other causes which in effect fix the magnitude of the least change in electromotive force producing a discernible change in the deflection of the galvanometer, are reduced to half. This results from the fact that, in effect, the method doubles the sensitivity of the galvanometer to a lack of balance of the potentiometer without affecting its sensitivity to disturbances.

A potentiometer made by the Leeds & Northrup Co. and a potentiometer made by the Rubicon Co. are equipped for the use of this method. Tests of these potentiometers have shown that in the measurement of very small electromotive forces, under normal laboratory conditions, an accuracy of 0.01 microvolt may be realized. In the paper which follows this<sup>6</sup> a potentiometer designed especially for the use of this method is described somewhat in detail, and results obtained in tests are given. The method described here is an adaptation to potentiometer measurements of the method which for many years has been used in those bridge measurements in which the accuracy of balances is such that the products of currents and resistances are matched to 0.1 and occasionally to 0.001 microvolt. However, it should be pointed out that, in bridge measurements, the resistance to

<sup>6</sup> R. P. Teele and S. Schuhmann, *A potentiometer for measuring voltages of 10 microvolts to an accuracy of 0.01 microvolt*, NBS J. Research **22**, 431 (1939) RP1195.

an electromotive force in the galvanometer branch is not momentarily increased or decreased by the operation of the double-pole double-throw key or switch, since it is located in the battery branch. Nevertheless, the electromotive force induced in the bridge and galvanometer leads on reversing the current, would, in some cases, if not compensated, cause considerable movement of the galvanometer coil. One of the bridges is therefore equipped with a device for compensating this induced electromotive force. Furthermore, the double-pole, double-throw switch opens the circuit in the process of reversing connections, and it is not so constructed that it is free of thermoelectromotive forces. In addition, no sensitivity keys are used in the galvanometer branch. Consequently, the special equipment necessary to fully realize the advantages of the method and some of the initial steps in the establishment of balances are not the same in bridge measurements as in potentiometer measurements.

WASHINGTON, January 31, 1939.